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Effects of Simulated Acidic Rain Applied Alone and in Combination with Ambient Rain on Growth and Yield of Field-Grown Snap Bean

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16. ABSTRACT

Field-grown snap bean plants were treated with simulated acidic rain applied either alone or in combination with ambient rain and the effects on growth and yield were determined. In plots where ambient rain was excluded, a retractable canopy was activated to shield the crop. Four levels of acidity at pH values of 5.0,4.2,3.4 and 2.6 were applied in four replicate treatments and the experiment was conducted in two successive years(1981 and 1982).

In plots that received only simulated rain, yield was not adversely affected by acidic rain; in 1981, a positive linear relationship was present between acidity of simulated rain and yield, but in 1982, no effect was found. In contrast, in plots that received both simulated and ambient rain, a negative linear relationship between acidity in simulated rain and yield was observed in both years. Previous research performed without exclusion of ambient rain should be re-evaluated, and current research should provide for control of water supply as well as deposition of hydrogen ions and other components in rain.

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EFFECTS OF SIMULATED ACIDIC RAIN APPLIED ALONE AND IN COMBINATION WITH AMBIENT RAIN ON GROWTH AND YIELD OF FIELD-GROWN SNAP BEAN

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ABSTRACT

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Field-grown snap bean (*Phaseolus vulgaris* L. cultivar 'Provider') plants were treated with simulated acidic rain applied either alone or in combination with ambient rain and the effects on growth and yield were determined. In plots where ambient rain was excluded, a retractable canopy was activated to shield the crop. Four levels of acidity at pH values of 5.0, 4.2, 3.4 and 2.6 were applied in four replicate treatments and the experiment was conducted in two successive years (1981 and 1982).

In plots that received only simulated rain, yield was not adversely affected by acidic rain; in 1981, a positive linear relationship was present between acidity of simulated rain and yield, but in 1982, no effect was found. In contrast, in plots that received both simulated and ambient rain, a negative linear relationship between acidity in simulated rain and yield was observed in both years. Changes in yield were due to effects on the number of pods per plant. Vegetative mass and size of pods were unaffected by acidity in simulated rain in either experimental condition. Apparently, acidic rain has no detrimental effect on growth or yield of snap bean, especially under conditions of normal water supply. Plant response to acidic rain, however, was altered by the presence of ambient rain. Consequently, previous research performed without exclusion of ambient rain should be re-evaluated, and current research should provide for control of water supply as well as deposition of hydrogen ions and other components in rain.

INTRODUCTION

Rainfall of the eastern U.S. has been shown to contain elevated levels of free hydrogen ions (H^+) (Dana and Rothert, 1983). This condition, termed "acid rain", has raised concern over its potential effects on agricultural and natural ecosystems (National Research Council, 1981). Investigations with agricultural crops have been designed to determine dose—response relationships between productivity of plants and acidity of simulated rain treatments (Jacobson, 1980). Experimental conditions have differed between investi-

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gations, and some have been shown to affect plant response to acidity. Specifically, based on the occurrence of lesions, foliage of greenhouse-grown plants has been injured at lower concentrations of H^+ in solution than foliage of field-grown plants (Irving and Miller, 1981; Cohen et al., 1982). Consequently, field experiments are needed to avoid over-estimation of the effects of acidic rain on growth and yield of plants.

Owing to the expense and technology involved in excluding ambient rain from experimental sites, field investigations were initially conducted by interspacing simulated rain treatments between ambient rain events (Irving and Miller, 1981; Cohen et al., 1982; Troiano et al., 1982; Evans et al., 1982). However, the total amount of water received by plants or additional inputs of components from ambient rain could affect plant response. Thus, devices have been developed that permit plants to be grown under natural conditions with ambient rain events excluded from experimental areas (Jacobson and Troiano, 1983). A retractable canopy for exclusion of ambient rain was constructed for this investigation to permit a study of the effects of acidity in simulated rain on growth and yield of snap bean (*Phaseolus vulgaris* L. cultivar 'Provider'). Additionally, plants were grown in an adjacent site and received the same simulated rain treatments as well as ambient rain events. Thus, a second objective was to investigate the influence of experimental methodology on plant response to acidic rain.

MATERIALS AND METHODS

Experimental design

The effects of acidity in simulated rain on growth and yield of snap bean were determined under two experimental conditions; one where only simulated rain treatments were received by plants and another where simulated rain treatments were confounded by additional exposure to ambient rain. In each experimental condition, four levels of acidity were applied to four replicate plots at pH values of 5.0, 4.2, 3.4 and 2.6. In protected plots (plots that received only simulated rain events), treatments were applied in randomized complete blocks, and in unprotected plots (plots that received simulated rain interspaced with ambient rain events), treatments were applied in a 4×4 Latin square. The experiment was replicated for two years (1981 and 1982).

Field-site

The field-site consisted of two adjacent areas. One area (27 × 6 m) was protected from ambient rain by an automated, retractable canopy, and another site (12 × 12 m) was open to ambient rain. Both areas received full sun and wind during non-rainy periods.

The soil was a moderately well-drained silty loam hapludalf (Cline and

Marshall, 1977). After fertilizer was applied, soil samples were taken from each plot. The soil was then cultivated. Five soil cores (15 cm deep) from each experimental plot were pooled and the composite sample analyzed for inorganic nutrients by the Cornell University Testing Laboratory (Ithaca, NY 14853).

Plant culture

The experimental areas were plowed, disked, fertilized with 10—10—10 N—P—K at a rate of 60 kg N ha^{-1}, and rototilled each year. Seeds of snap bean were treated with captan and *Rhizobium* inoculum, and hand-planted on 14 July and 12 June in 1981 and 1982, respectively. In 1981, ambient rainfall occurred directly after seeding and was sufficient to initiate growth, but in 1982, the period after seeding was dry so plots were irrigated. Rows were spaced 45 cm apart and within rows, plants were spaced 7.5 and 6 cm apart producing planting densities of 300 000 and 370 000 plants ha^{-1} in 1981 and 1982, respectively. Neither fungicides nor insecticides were applied after planting because the incidence of disease and insect infestation was minimal in both years.

Soil moisture was monitored with irrometers (Irrometer Company, Inc., Riverside, CA 95216) that had been calibrated in the laboratory. The scale on the irrometer ranged from 0 to 100 and corresponded to 0 to -1 atmosphere of soil water deficit. Plots were irrigated when irrometers read 65 or higher. Plants that received simulated or ambient rain required little or no irrigation, but, in the protected site, untreated plots required routine irrigation. In 1982, irrigation was performed with a hand-held hose and care was taken not to wet the foliage. In 1982, a trickle irrigation system (Chapin Watermatics, Watertown, NY 13601) was installed between each row of plants. Portions of irrigation line that were located in plots receiving simulated rain treatments were covered to prevent these areas from receiving additional water.

At harvest (57 days after seeding in 1981 and 53 days after seeding in 1982), plants were cut at ground level. In each plot, 0.67 m from each of 2 rows was sampled for a total of 16 and 20 plant samples in 1981 and 1982, respectively. Marketable pods (>12 cm in length) were separated from non-marketable pods (<12 cm in length) and the number and fresh weight were recorded. Plant material was dried in a forced draft oven at 80°C for 48 h, after which the masses of the stalk (stems and leaves) and marketable pods were taken.

Treatment application

Simulated rain solutions were prepared (Table I) and individually stored in 946-l polyethylene tanks. The solutions for each treatment were circulated around the perimeter of the field-site through 2.5-cm PVC pipe by a stain-

TABLE I

Concentration ($\mu m\ l^{-1}$) of principal chemical species in solutions used to simulate acidic rain

pH	Hydrogen (H^+)	Sulfate (SO_4^{2-})	Nitrate (NO_3^-)	Chloride[a] (Cl^-)	Ammonium[a] (NH_4^+)	Calcium[a] (Ca^{2+})	Potassium[a] (K^+)	Sodium[a] (Na^+)	Magnesium[a] (Mg^{2+})
5.0	10	12	9	3.5	20.5	2.8	1.4	1.2	0.8
4.2	63	33	25	3.5	20.5	2.8	1.4	1.2	0.8
3.4	398	154	118	3.5	20.5	2.8	1.4	1.2	0.8
2.6	2512	916	706	3.5	20.5	2.8	1.4	1.2	0.8

[a]Concentration of background ions determined for a representative ambient rain event monitored at a MAP3S site near Ithaca, NY, for the period June—October of 1978 and 1979.

less steel centrifugal pump. Simulated rain solutions were applied to plants through stainless steel nozzles (4.3W, Spraying Systems, Wheaton, IL 60187 in 1981, and 11142205, Spraco, Nashua, NH 03060 in 1982) that were connected by 1.25-cm polyethylene tubing to the main circulating system. The nozzles were located 2 m above ground level and were operated at hydraulic pressures of 0.84 and 0.56 kg cm^{-1} in 1981 and 1982, respectively. The mass median diameter of droplets was approximately 1.0 mm and rates of deposition were 0.86 and 0.68 cm h^{-1} in 1981 and 1982, respectively, when operated intermittently (10 min on and 10 min off). Treatments were initiated at the time unifoliolate leaves were fully expanded (Table II).

TABLE II

Description of ambient and simulated rain events received by plants during the period of growth

Time-interval	Number of events	Ambient rainfall deposition (mm)	pH[a]	Simulated rain	
				Number of events	Deposition (mm)
1981					
14 — 21 July	1	19[b]	3.98	—	—
21 July — 2 September	11	153	3.90	11	91
3 — 9 September	4	52[b]	4.13	—	—
1982					
13 June — 1 August	11	108	3.94	14	143
2 — 4 August	2	7[b]	3.99	—	—

[a]Volume weighted mean.
[b]Amount deposited on plants in both protected and unprotected sites.

Exclusion of ambient rain

The protective, retractable canopy was a modified PowerPull (Wadsworth Controls, Arvada, CO 80001). The device was free-standing, with two rows of supports that were 37 m apart and orientated north—south. A 27.4 × 12.2 m polyethylene rip-stop tarpaulin was secured lengthwise to the lower row of supports and was normally bunched up near the lower purlin. At the onset of an ambient rain event, the leading edge was drawn towards the upper purlin by a cable—pulley—sprocket system that was driven by a gear-

head motor. The drive motor was triggered by a rain sensor or could be activated manually. Thirty minutes after the rain sensor had dried, the drive motor was activated in a reverse mode and the tarpaulin drawn back to the lower purlin. Due to mechanical problems, plants in protected plots in 1981 received 5.23 cm of ambient rain during the last 6 days before harvest (Table II).

Environmental monitoring

Each ambient rain event was sampled by an automatic wet/dry precipitation collector (Aerochem Metrics, Miami, FL 33143), and pH was determined in the laboratory with a Metrohm EA109 pH electrode and Metrohm E536 potentiograph (Brinkman Instruments, Inc., Westbury, NY 11590) (Table II). Data for the maximum and minimum daily temperature and for total solar radiation at a site in Ithaca, New York, were obtained from monthly meteorological summaries (New York Climate Office, Cornell University, Ithaca, NY 14853). The average maximum and minimum daily temperatures for the period of growth were 24.2 and 13.6°C in 1981 and 26.3 and 13.4°C in 1982. Total solar radiation for the period of growth was 9×10^8 and 11×10^8 J m^{-2} in 1981 and 1982, respectively.

Statistical methods

Data were analyzed by the General Linear Models Procedure of the S.A.S. (S.A.S. Institute, 1979) package through Cornell Computing Services. The effects of acidity in simulated rain on the fresh and dry mass and number of pods produced per plant and on dry mass per marketable pod were analyzed by analysis of variance (ANOVA). Treatment sums of squares for the effects of acidity in simulated rain were fully partitioned into orthogonal contrasts for regression (Snedecor and Cochran, 1980). Subsequent regression analyses were conducted to obtain estimates for the parameters of a linear-polynomial dose–response function of the form

$$Y = A + B_1\text{pH} + B_2\text{pH}^2 + B_3\text{pH}^3 + C_1P_1 \ldots\ldots C_NP_N \quad (1)$$

where Y = measured response, A = intercept of the function, pH = the concentration of H^+ in treatment solutions, $B_1 - B_3$ = parameters defining effects of acidity, $P_1 - P_N$ = variables included in function to account for significant positional effects, i.e., blocks, columns, etc., and $C_1 - C_N$ = parameters defining positional effects. Only estimates of the parameter for the effect of pH are reported.

RESULTS

Soil characteristics

The mean, minimum and maximum values for the content of the major soil variables after application of fertilizer are given by year and location of

plots (protected and unprotected plots) (Table III). Because of the previous application of fertilizer to an earlier unrelated planting, the concentrations of nitrogen, phosphorus and potassium were higher in 1982 than in 1981. Snap bean was the only crop seeded in 1981.

Soil acidity, nitrogen and potassium levels were higher in protected plots than in unprotected plots in both years (Table III). An application of lime to the site in 1981 was ineffective in equalizing soil acidity. Since fertilizer was evenly broadcast over the entire site in both years, the differences in concentration of soil variables between locations may have been due to inherent differences in soil acidifying properties.

As reflected by the irrometer readings, plots that received both simulated and ambient rain events experienced extended periods of wetness and lesser soil water deficit than plots that received only simulated rain events (average irrometer readings for the experimental period corresponding to approximately -30 vs. -280 and -280 vs. -400 millibars for plots that received simulated and ambient rain vs. plots that received only simulated rain for 1981 and 1982, respectively).

TABLE III

Mean, minimum and maximum values (ppm) for nitrogen, phosphorus and potassium content and acidity of soil in protected and unprotected plots after application of fertilizer

Statistic	Nitrogen		Phosphorus		Potassium		Soil acidity	
	1981	1982	1981	1982	1981	1982	1981	1982
Protected plots								
Mean	94	149	8	19	191	203	5.6	5.5
Minimum	60	75	3	10	100	120	5.1	5.1
Maximum	160	220	17	25	320	300	5.8	5.9
Unprotected plots								
Mean	73	90	7	21	119	151	6.0	6.0
Minimum	30	60	3	11	60	110	5.4	5.2
Maximum	140	160	14	30	220	200	7.2	7.1

Vigor and growth of plants between protected and unprotected plots

Observations on the rate of canopy development indicated that the growth-rate of plants exposed to both ambient and simulated rain events (unprotected plots) initially lagged behind those exposed only to simulated rain (protected plots). At harvest, the dry mass per marketable pod was less in unprotected plots than in protected plots (Table IV), and overall means for unprotected vs. protected plots of 0.51 vs. 0.63 and 0.45 vs. 0.50 g/pod for 1981 and 1982, respectively. No other consistent differences in growth were observed between protected and unprotected plots.

Visible injury on plant foliage was not observed in either year, even at the most acidic simulated rain treatment (pH 2.6).

TABLE IV

Mean values for components of growth and yield of snap bean plants grown in plots either protected or unprotected from ambient rain and exposed to simulated acidic rain solutions

Year and treatment	Fresh mass of marketable pods (g/plant)	Dry mass of marketable pods (g/plant)	Number of marketable pods (per plant)	Dry mass per marketable pod (g/pod)	Dry mass of stalk (g/plant)
Protected plots					
1981					
pH 5.0	30.44[a]	2.38	3.94	0.605	5.60
4.2	30.50	2.40	4.09	0.591	4.36
3.4	35.38	2.99	4.59	0.663	5.53
2.6	35.15	2.82	4.99	0.575	5.31
1982					
pH 5.0	39.89	2.91	6.10	0.477	8.82
4.2	45.04	3.39	6.48	0.523	9.27
3.4	34.58	2.55	5.21	0.486	9.41
2.6	44.53	3.37	6.55	0.512	8.35
Unprotected plots					
1981					
pH 5.0	32.92	2.33	4.58	0.522	6.19
4.2	31.94	2.36	4.56	0.513	4.99
3.4	28.90	2.15	4.21	0.494	5.34
2.6	27.01	2.04	3.86	0.520	4.65
1982					
pH 5.0	32.22	2.28	5.13	0.442	9.94
4.2	36.70	2.61	5.66	0.459	10.31
3.4	30.73	2.19	4.93	0.442	11.02
2.6	29.43	2.08	4.73	0.436	10.98

[a]Mean of 4 replicate plots.

Effects of acidity on components of growth and yield

Protected plots

Statistical analyses for fresh and dry mass and number of pods produced per plant were conducted by year because of significant interactions between acidic rain treatments and years (Tables IV and V). In 1981, treatment sums of squares for the effects of acidity were mainly partitioned into the linear contrast (Table VI) and regressions were significant; dry mass and number of pods per plant increased with increase in acidity (decrease in value of pH in regression) of simulated rain (Table VII). In 1982, treatment sums of squares for the effects of acidity were mainly partitioned into the cubic contrast for regression, but regressions were not significant. This result indicated that there was no consistent effect of acidity in 1982. Effects of acidity on fresh mass of pods were similar to those observed with dry mass; in 1981, treatment sums of squares were mainly partitioned into the linear contrast for regression, and in 1982, no effect was indicated in regression analyses (Table VI). The dry mass of stalk (Table V) and dry mass per marketable pod in either year (Table VI) were not significantly affected by acidity of simulated rain.

Unprotected plots

The interaction between acidic rain treatments and years was not significant. Treatment sums of squares for the effects of acidity on fresh and dry

TABLE V

Analyses of variance for the effects of acidity in simulated rain on components of growth and yield of snap bean plants grown in plots that were either protected or unprotected from ambient rain

Source of variation	DF	Mean square[a] for:				
		Fresh mass of marketable pods	Dry mass of marketable pods	Number of marketable pods	Dry mass per marketable pod[c]	Dry mass of stalk
Protected plots						
Years (*Y*)	1	530.2396**[b]	1.3382**	22.6498**	952.0554**	113.2174**
Blocks (*B*)	3	114.0945*	0.4883	2.433**	66.3702	3.7483
Acidity (*A*)	3					
Linear	1	50.5800	0.6020	1.3943	2.8232	0.0908
Quadratic	1	10.1250	0.0094	0.7194	43.1681	0.1271
Cubic	1	68.0196	0.2639	1.4273	10.5884	2.2059
Y x *B*	3	52.2400	0.2492	0.9715	14.2129	1.6544
Y x *A*	3					
Y x Linear	1	24.1647	0.1876	1.2666	7.4672	0.2373
Y x Quadratic	1	12.9795	0.1405	0.2632	14.1509	3.1771
Y x Cubic	1	211.0024**	1.8649**	2.2062*	154.0500*	0.8449
Residual	18	25.5881	0.1680	0.4397	23.7696	2.5049
Unprotected plots						
Years (*Y*)	1	34.5073	0.0389	5.2318**	407.6531**	222.0462**
Columns (*C*)	3	35.6039	0.1458	0.4824	0.8884	11.5421**
Rows (*R*)	3	73.6487*	0.3699*	2.5114**	20.2346	6.9417*
Acidity (*A*)	3					
Linear	1	123.0431*	0.4392*	1.9478*	0.2342	0.0208
Quadratic	1	22.2945	0.1681	0.5458	0.4775	0.0056
Cubic	1	33.6998	0.1946	0.4600	4.6816	1.3631
Y x *C*	3	21.5190	0.1330	0.3587	26.0693**	1.4183
Y x *R*	3	67.0164*	0.4043**	0.7863	49.2009**	4.5597
Y x *A*	3					
Y x Linear	1	4.1958	0.0006	0.0353	1.7668	6.5707
Y x Quadratic	1	11.8706	0.0469	0.0848	5.3442	0.4329
Y x Cubic	1	14.1432	0.0524	0.2246	0.7764	0.2211
Residual	12	19.7169	0.0718	0.2628	4.5902	1.6213

[a]Mean squares derived from Type I sums of squares for sequential fit of terms in a General Linear Model (SAS).
[b]Mean squares that would give *F*-ratios greater than the tabulated values for the *F*-distribution at α=0.05 and α=0.01 are denoted by * and **, respectively.
[c]Values multiplied by 100 to reduce errors due to rounding-off during analyses.

mass and number of pods per plant were mainly partitioned into the linear contrast for regression (Tables IV and V). In contrast to the response in protected plots, regression analyses indicated decreases in mass and number of pods with increase in acidity in simulated rain (Table VII). As in protected plots, dry mass of stalk and dry mass per marketable pod were unaffected by acidity of simulated rain.

DISCUSSION

The results obtained from plants exposed only to simulated rain indicated that increases in acidic components in rain were not detrimental to growth or yield of field-grown snap bean. In fact, the dose-response in 1981 suggested the possibility of beneficial effects on yield. In 1982, no effect was observed, even though a greater amount of simulated rain was deposited

TABLE VI

Analyses of variance conducted by year for the effects of acidity in simulated rain on components of growth and yield of snap bean plants grown in plots that received only simulated rain events

Source of variation	DF	Mean square[a] for:							
		Fresh mass of marketable pods		Dry mass of marketable pods		Number of marketable pods		Dry mass per marketable pod[c]	
		1981	1982	1981	1982	1981	1982	1981	1982
Blocks	3	114.0094[b]	52.2431	0.3744	0.3611	2.3956*	1.0093	0.7880	16.7951
Acidity									
Linear	1	72.3331	2.4117	0.7308*	0.0588	2.6594*	0.0015	0.5538	9.7366
Quadratic	1	0.0885	23.0160	0.0386	0.1112	0.0562	0.9264	53.3752	3.9438
Cubic	1	19.7111	259.3080*	0.3629	1.7660*	0.0422	3.5913*	122.7065	41.9319
Residual	9	22.2313	28.9448	0.1167	0.2194	0.4531	0.4263	36.2693	11.2699

[a]Mean squares are derived from Type I sums of squares for sequential fit of terms in a General Linear Model (SAS).
[b]Mean squares that would give *F*-ratios greater than the tabulated values for the *F*-distribution at α=0.05 and α=0.01 are denoted by * and **, respectively.
[c]Values multiplied by 100 to reduce errors due to rounding-off during analyses.

TABLE VII

Statistics for significant regression of components of yield in snap bean on acidity of simulated rain (1981)

	$\beta_1 \pm SE^a$	Correlation[b] coefficient
Protected plots		
Fresh mass of pods/plant	-2.377±1.250	0.65
Dry mass of pods/plant	-0.239±0.102	0.56
Number of pods/plant	-0.456±0.172	0.70
Unprotected plots		
Fresh mass of pods/plant	2.190±0.938	0.51
Dry mass of pods/plant	0.131±0.060	0.56
Number of pods/plant	0.276±0.119	0.61

[a]Coefficient for effect of acidity in simulated rain ± standard error.
[b]Multiple correlation coefficient for complete model that includes terms for position effects, i.e. years and blocks (see Table V).

(91 vs. 143 mm for 1981 and 1982, respectively). If deposition of acidic components in rain is beneficial to yield, then differences in plant response cannot be attributed to application of treatments. Variation in environmental conditions between years may have accounted for the differences in response. However, initial levels of N, P and K in the soil were greater in 1982, which may have attenuated the potential for stimulation of yield by additions of potential nutrients from acidic rain treatments. Further investigations are needed to evaluate the environmental and edaphic conditions that promote potential growth-stimulating effects of acidic rain.

In contrast to the response observed in protected plots, detrimental effects of acidic rain on yield were observed in unprotected plots. Two differences between the protected and unprotected sites were soil conditions and the presence of ambient rain. With respect to agricultural soils, one might expect that soils that are more acidic would be more sensitive to inputs from acidic rain (Alexander, 1980). Thus, adverse effects of acidic rain on yield would have been expected to occur in protected plots because those soils were more acidic. The opposite response were observed. Therefore, differences in soil properties between experimental sites probably did not account for the difference in plant response to simulated acidic rain.

Owing to additions by ambient rain, the total amount of water received by unprotected plots was 3.5 and 1.8 times greater than in protected plots in 1981 and 1982, respectively. Increased availability of water could change the soil environment and alter patterns of plant growth (Lal and Greenland, 1979). With respect to *P. vulgaris*, supplemental irrigation during periods of water deficit in soils has increased productivity (Magalhaes et al., 1979; Stansell and Smittle, 1980), but short periods of waterlogging have adversely affected growth and yield of snap bean (Forsythe et al., 1979) and other legumes (Minchin et al., 1978; Cannell et al., 1979; Wien et al., 1979).

Adverse effects of waterlogging may be caused by a number of factors, such as production of hormonal imbalances or induction of toxic reactions to components in soils (Crawford, 1982). In unprotected plots, the slow initial growth of plants and delay in development of pods may have resulted from periods of waterlogging. Consequently, detrimental effects of acidic rain may have developed from interactions with physiological changes induced in plants by the increased supply of water.

The influence of ambient rain may have been expressed through other processes; plant response may have been affected by acidic components in ambient rain or it may have been mediated by the physical presence of rain (i.e., a greater total period of leaf wetness in unprotected plots). Since vegetative mass was unaffected by treatment, and effects on yield were caused by changes in the number of pods produced per plant, processes of flowering or seed-set may have been affected. Determination of the exact mechanism could be difficult because of the nature of the response.

Regardless of the mechanism by which ambient rain modified plant response, it is important that the dose—response function, and consequently conclusions concerning the effects of acidic rain on plant yield, were drastically altered by the experimental conditions. Hence, previous research performed without exclusion of ambient rain must be re-evaluated and new investigations should provide for control of total deposition of water as well as other components in rain.

In summary, growth or yield of snap bean was not adversely affected by increased acidity when only simulated rain treatments were received by plants. Exposure to ambient rain, however, appeared to alter plant response to simulated acidic rain treatments, so that a negative linear relationship was observed between the level of acidity in simulated rain and yield. The increase in supply of water may have altered patterns of plant growth and, subsequently, response to acidic rain. Hence, an understanding of how environmental and edaphic conditions regulate plant response to acidic components in rain would help interpretation of results obtained from different experimental conditions.

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